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A Preliminary Assessment of the Integrated Crop Management Practice

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Abstract

The integrated crop management (ICM) practice, also known as special practice 53 (SP-53), was instituted on a trial basis in 1990 under the Agricultural Conservation Program. The Agricultural Stabilization and Conservation Service administers the program, which provides cost sharing to encourage farmers to adopt systems incorporating integrated pest management and nutrient management practices. Analysis of the first year of ICM, based on a sample of four crops (corn, soybeans, wheat, cotton) grown in four States (Nebraska, Iowa, North Dakota, Mississippi), indicates some limited success. The primary effect of ICM appears to have been reduced nitrogen fertilizer use. Use of other fertilizers and pesticides, however, remained generally unaffected. ICM had little or no effect on crop yields. Leaching and runoff potential for pesticides was apparently reduced in some instances, while increased in others.

Keywords: Fertilizers, pesticides, water quality, cost sharing.

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Introduction

The integrated crop management (ICM) practice, also known as special practice 53 (SP-53), was instituted in 1990 on a trial basis as part of the Agricultural Conservation Program (ACP). The Agricultural Stabilization and Conservation Service (ASCS) administers the practice, which encourages farmers to adopt management systems incorporating integrated pest management and nutrient management practices. ICM provides 75-percent cost sharing, not exceeding $7 per acre for most field crops or $14 per acre for horticultural and specialty crops. Cost sharing is made available for up to 3 years for such things as pest scouting services, soil testing, or the rental of specialized machinery.[1]

When first introduced, the goal of ICM was to reduce pesticide and/or fertilizer use on participating fields by 20 percent or more. The goal was later changed to "promoting the efficient use of pesticides and fertilizers in an environmentally sound and economical manner." In 1990, the program was generally limited to no more than 5 counties per State and 20 farms per county.

This report describes a preliminary assessment of the effects of the ICM program. The analysis was based only on the first year of ICM implementation and on just a few areas of the country. Nevertheless, the results may be useful in determining whether to continue or expand the practice. The results may also be useful to those interested in water quality and programs for reducing the environmental effects of agricultural chemical use.

The Economics of the ICM Program

ICM can be viewed in either of two ways for analytical purposes. First, as a demonstration program, ICM's main goal is to educate farmers about alternative agricultural production techniques. The provision of cost sharing helps to overcome the initial reluctance of farmers about changing production practices. Because cost sharing is limited to 3 years, the presumption is that farmers will gain experience with the techniques, find in most cases that they are acceptable (that is, profitable), and continue their use even after cost sharing has ended. Thus, the need for analysis is primarily based on helping farmers anticipate the implications of including ICM in their operation, possibly by publishing yield and profitability results. A full social benefit-cost analysis is not necessarily required.

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[1]A more complete list of techniques used in the program includes monitoring insects and weeds, soil tests, additional cultivations, crop rotations, ridge tilling, chisel tilling, increased seeding rates, banded and spot spraying of pesticides and fertilizers, manure testing, tissue sampling, side dressing, and split fertilizer applications. Costs were also shared for consultation and planning fees, equipment rental (high-pressure sprayers, ridging equipment, fertilizer equipment, planters, banding equipment, air seeders), additional physical labor, and the use of more expensive, less toxic chemicals.

ICM can also be viewed as an experimental stage in the development of potentially larger programs to reduce agricultural nonpoint source pollution using farmer subsidies. Impairment of water quality from agricultural pesticide and fertilizer use is increasingly seen as a real cost of production, in the sense that society sacrifices valued resources to obtain agricultural goods. From society's standpoint, overuse occurs when the degradation of these useful resources (for example, fish habitat) is not compensated by equal or greater gains in the value of agricultural production. However, because the farmer does not bear the full cost of these externalities, they are not considered in farm-level decisionmaking. Therefore, in the unregulated market, too much environmental degradation will probably occur.

When viewed in this second way, ICM subsidizes alternative inputs such as pest scouting services, in effect, changing relative input prices.[2] The Government, to obtain the benefits of improved environmental quality, agrees to pay indefinitely part of the farmers' costs of adopting beneficial ICM practices. Without the subsidy, the farmer does not adopt ICM.[3] With less than a 100-percent subsidy, farmers must receive production benefits at least as great as the portion of cost they must pay. With the program, the farmers' prior non-ICM choices are no longer optimal, and input use is adjusted to the new relative prices.

From this perspective, the key question is whether the level of subsidy required to convince a farmer to adopt and continue use of ICM and the resulting distortions introduced into the agricultural sector are worth the resulting improvements in environmental quality. The answer to this question requires an understanding of how the economy fares under ICM, compared with the next best alternative, and how environmental quality changes when ICM is adopted. This understanding is the basis for conducting a full social benefit-cost analysis and is the point of view adopted in this report.

One means of performing such an analysis would be to construct a model of the general economy. However, given the small size of the ICM program relative to the rest of the economy, such an approach is unnecessary, and a simple partial equilibrium approach suffices. If one assumes a competitive market in inputs and outputs, current prices for inputs and outputs can be used as reasonable measures of marginal costs and benefits to society.[4] In other words, a benefit-cost model, using current prices, can be used to analyze the effects of ICM.[5]

One can consider the social cost of ICM as the value of additional resources used in the production of the preferred inputs (such as scouting services), less the value of resources freed from production of the substituted inputs (such as chemical applications), plus any resulting changes in the value of agricultural outputs. At the margin, price times quantity can be used to measure these values. Thus, the social cost of ICM equals:

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[2]Corrective charges are another alternative to rectify this market failure. For example, given a measure of the marginal damage caused by additional fertilizer runoff, and given that this damage can be converted into monetary terms, then a per unit of runoff charge theoretically could be levied on the farmer. The charge serves as a price for fertilizer runoff, inducing the farmer to adjust practices accordingly. As with any other priced input, the farmer will equate the value of augmented production (associated with increases in fertilizer runoff) to this charge.

[3]A non-ICM technology is presumably most profitable; otherwise, the risk-neutral farmer would adopt ICM in the absence of any subsidy.

[4]The existence of extensive agricultural programs will distort observed market prices for both inputs and outputs, in the sense that they do not necessarily measure full social cost or benefit.

[5]Further information on the theoretical basis for the cost-benefit model is available in appendix B.

$$SC_{ICM} = P_Y[Y_0 - Y_1] - P_A[A_0 - A_1] - P_B[B_0 - B_1] \tag{1}$$

where A represents non-ICM inputs, B represents ICM inputs such as pest scouting, Y is agricultural production, P is input and output prices, and subscript 0 is without ICM participation and subscript 1 is with ICM participation. One presumes that $(A_0 - A_1)$ is positive, $(B_0 - B_1)$ is negative, and $(Y_0 - Y_1)$ is indeterminant. Equation 1 can be reformulated as follows:

$$\begin{aligned} SC_{ICM} &= [(P_Y \times Y_0) - (P_A \times A_0) - (P_B \times B_0)] - [(P_Y \times Y_1) - (P_A \times A_1) - (P_B \times B_1)] \\ &= \quad \Pi_0 \quad - \quad \Pi_1 \end{aligned} \tag{2}$$

In other words, the social cost of ICM can be assessed simply by measuring the change in farm profits. The ICM subsidy is excluded because it is merely a transfer payment.[6] In a controlled experiment, measurement of changes in farm profit might be relatively direct. However, many factors influence farm profitability. For example, an increase in crop prices, or unusually good weather, might yield a temporary increase in profit that has nothing to do with the adoption of an ICM technology.

To control for such factors, one must use multiyear measures of input use, output production, and the presence of Government programs to construct a model of farm behavior. The effects of ICM, both on farm profitability and on input use and output production, could then be analyzed through appropriate simulations.[7] The accuracy of such a model is a function of the breadth and quality of data on input demand and output production. At a minimum, input, output, and price data would have to be gathered over a wide range of farms before ICM and after ICM. These data would also need to be collected on a multiyear basis, because any given year of an ICM program may not be indicative of average performance, especially since careful selection of crop rotations may be one way of reducing overall input use.

ICM's putative goal is to lessen adverse agricultural effects on the environment. Therefore, analysis of ICM requires monetary measures of the benefits from improvements in environmental quality. The measurement of these benefits is problematic for two reasons. First, the lack of prices for the commodity "environmental quality" necessitates use of indirect measures of value. Second, these measures depend upon noneconomic information on the physical and biological changes given adoption of ICM.

Thus, estimation of the environmental benefits provided by ICM requires the resolution of the following questions:

1. What physical effects, in terms of reduced chemical loadings, does ICM produce?
2. What are the associated ecological effects?
3. How does society value these ecological effects?

Questions one and two are outside of the domain of economics and must be answered by physical and biological scientists. Question three, while difficult, is within the domain of economics, and there are several means for ascertaining such values. First, one can attempt to infer these values through revealed preference

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[6]Note that the focus is on economic efficiency, rather than other potential social goals. Also, we omitted costs associated with program administration. These costs are assumed to be small, and their inclusion in the benefit-cost calculation would be relatively straightforward.

[7]For example, ICM can be modeled as a price subsidy on certain preferred inputs (such as scouting services). The social cost of the ICM program could then be calculated by multiplying these new inputs and outputs by the nonsubsidized prices, and comparing the resulting social net profit to the profit achieved when prices are not subsidized.

techniques that examine actual behavior. Two examples of revealed preference techniques are travel cost analysis and hedonic price analysis, both of which can be extended to incorporate environmental quality. Second, contingent valuation techniques can be used to elicit the value of environmental improvements, with respondents directly valuing postulated changes in environmental quality. A combination of contingent valuation and revealed preference techniques is often used to estimate the benefit of improvements in environmental quality. A more detailed discussion of these techniques is offered in appendix B.

Description of Analysis

Although this report provides an initial assessment of ICM, we did not attempt to compare the practice's benefits with its costs. Such a comparison would require more information than could be obtained from existing ASCS program records. A more complete study, as outlined in the previous section, would involve measuring changes in total farm profitability and benefits to ground water, surface water, and human health through the use of fewer or more environmentally benign chemicals or fertilizers. Such a study would require detailed farm and environmental data covering a number of years.

Due to data and time limitations, this preliminary assessment was limited to answering the following questions:

1. Did fertilizer use change as a result of ICM, and if so by how much?
2. Did pesticide (herbicide and insecticide) use change as a result of ICM, and if so by how much?
3. Did ICM have any effect on crop yields, and if so by how much?

Two additional questions should be addressed:

4. What was the effect of ICM on the environment?
5. What was the effect of ICM on farm profitability?

Because of the lack of information on input and output quantity and prices, and on environmental effects and values, we could not fully examine questions 4 and 5. Hence, the focus of the analysis was on questions 1 through 3.

These questions were answered by formal statistical tests on a crop-by-crop, area-by-area basis where data could be assembled and analyzed. Other questions, such as what farmers thought of the program, were addressed less formally through compilation of comments written by farmers about their ICM participation. Still other questions, such as changes in the overall mix of herbicides used, may be answered in part by inspection of the results.

To provide valid answers to the first three questions, it is necessary to compare input use and yields with ICM to what would have occurred without ICM. To compare chemical use and crop yields before and after ICM implementation would be misleading because any observed changes could be the result of influences other than ICM. For example, if 1990 was a bad year for corn compared with 1989 because of weather, then some or all of an observed decrease in yield from farms beginning ICM in 1990 may have nothing to do with the use of ICM. What is needed then is a control group, similar to those participating in ICM in all important respects except for participation in ICM.

Because formal control groups with which yields and input use might be compared did not exist, we used as a proxy data on yields, fertilizer use, and pesticide application rates from the 1989 and 1990 Objective Yield Survey Cropping Practices Interviews (OYS) conducted by the National Agricultural Statistical Service (NASS). The interviews, conducted by enumerators who make field visits during the growing season, collect data on seeding, fertilizer use, pesticide use, tillage and planting operations, and miscellaneous information. Seven commodities are represented including corn, soybeans, wheat, cotton, rice, potatoes, and peanuts.

Depending upon the commodity, fields may be randomly selected from an area frame, a multiframe, or a stratified sampling technique.

To determine if ICM had an effect on corn grown in Nebraska, for example, the OYS data for corn grown in Nebraska in 1989 and 1990 were first analyzed to provide a benchmark for comparison.[8] Any significant observed changes in the OYS data would have to be the result of non-ICM factors (such as changing weather or pest pressure). Next, ICM program data for Nebraska corn in 1989 and 1990 for farmers beginning ICM in 1990 were analyzed relative to this benchmark.[9]

To elaborate on the method of analysis, let us say that the OYS average yield for corn grown in Nebraska increased from 1989 to 1990. The increase was statistically significant and amounted to 8 percent. Then, if we discover from the Nebraska ICM program data that corn yield for farmers who first applied ICM in 1990 also increased by a statistically significant 8 percent, we conclude that ICM had no net effect on corn yield in Nebraska. If, however, the yield for ICM participants declined by 8 percent, then relative to the OYS benchmark, we would conclude that ICM caused a net decrease in corn yields of approximately 15 percent.[10]

Because rotational changes occurred in some instances with ICM implementation, the analysis was conducted for the statistical average acre of a crop grown in a specific State. Pesticides and certain fertilizers are often applied only on a portion of the total acres of a crop in a given area. Thus, average chemical application rates may appear lower than normal label rates, because instances of positive use have been averaged with instances of zero use. Nevertheless, by analyzing the average acre, we are able to obtain a better idea of how ICM affects environmental quality over a broad area.

The first statistical test conducted on each crop-area combination was to determine if there was a statistically significant change (95-percent confidence level) in yield or application rates of fertilizer (nitrogen, phosphate, potash) or pesticides for the average acre surveyed in the 1989 and 1990 OYS (control group). This test can be written as:

$$H_{O_{OYS}}:\ \bar{X}_{89\ OYS} = \bar{X}_{90\ OYS} \tag{3}$$

$$H_{A_{OYS}}:\ \bar{X}_{89\ OYS} \neq \bar{X}_{90\ OYS} \tag{4}$$

where $\bar{X}$ is the mean value of the variable in question, and the subscripts refer to year and group (OYS = Objective Yield Survey Cropping Practices Interview, ICM = integrated crop management). Failure to reject equation 3, the null hypothesis, indicates that there is no statistically significant benchmark difference in the OYS between 1989 and 1990. Therefore, to determine if ICM had an effect, one need only to statistically compare 1989 and 1990 input use and crop yields for ICM participants. In this case, the test for ICM participants is as follows:

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[8]Control groups below the State level were also analyzed for comparison as discussed in the Results section.

[9]Although some ICM participants may have been among those surveyed for the 1990 OYS, the number of ICM participants relative to all farms surveyed in the OYS would be very small, introducing little or no bias into the analysis.

[10]Net Effect = (Actual Yield - Expected Yield) ÷ Expected Yield. So (0.92 -1.08) ÷ 1.08 = -0.15.

$$H_{O_{ICM}}: \quad \bar{X}_{89\ ICM} = \bar{X}_{90\ ICM} \tag{5}$$

$$H_{A_{ICM}}: \quad \bar{X}_{89\ ICM} \neq \bar{X}_{90\ ICM} \tag{6}$$

If equation 3 was first rejected, then the test for ICM participants is made relative to the percentage change observed in the OYS data. This action assumes that non-ICM variables affected each group in the same way. In other words, this assumes that weather patterns, relative input prices, and other factors affected ICM and non-ICM farmers alike. In this case, the hypothesis test for an ICM effect is as follows:

$$H_{O_{ICM}}: \quad \bar{X}_{89\ ICM} \cdot \left(1 + \frac{\bar{X}_{90\ OYS} - \bar{X}_{89\ OYS}}{\bar{X}_{89\ OYS}}\right) = \bar{X}_{90\ ICM} \tag{7}$$

$$H_{A_{ICM}}: \quad \bar{X}_{89\ ICM} \cdot \left(1 + \frac{\bar{X}_{90\ OYS} - \bar{X}_{89\ OYS}}{\bar{X}_{89\ OYS}}\right) \neq \bar{X}_{90\ ICM} \tag{8}$$

The Results section presents only net changes attributable to ICM participation. However, appendix A presents full results in order of the sequential hypothesis tests outlined above.

Data

Yield and input use characteristics before ICM (1989) and after ICM (1990) participation were gathered from a subset of ASCS program forms (ACP-313). These data consisted of 1,060 records taken from 351 farms, with each record representing a different field. The fields were located in 48 counties in the following 15 States: Illinois, Iowa, Kentucky, Maine, Maryland, Michigan, Mississippi, Missouri, Nebraska, North Dakota, Pennsylvania, Rhode Island, Tennessee, Virginia, and West Virginia. Only those crops and States for which there were sufficient observations to conduct statistical tests are reported in the Results section of this report. These included corn (378 observations) and soybeans (32 observations) in Nebraska, corn (75 observations) and soybeans (42 observations) in Iowa, wheat in North Dakota (128 observations), and cotton in Mississippi (100 observations). As indicated in the previous section, State-level control group yield and input use data came from the 1989 and 1990 Objective Yield Survey's Cropping Practices Interview.

From each data set, field-level fertilizer application rates for 1989 and 1990 were calculated in pounds per acre for nitrogen, phosphate, and potash. Pesticides were converted to pounds of active ingredient per acre. Only those pesticides used on 10 percent or more of the acres devoted to a particular crop are reported. Pounds of active ingredient for herbicides and, where used, insecticides were summed to give an indication of the overall use of herbicides and insecticides. Finally, means, variances, and degrees of freedom were calculated for yields, fertilizer applications, and pesticide applications within the six crop-region combinations.

Results

The net effects of ICM on yield, fertilizer, and pesticide use are presented in this section. The presentation begins with Nebraska corn and soybeans, then moves to Iowa corn and soybeans, and concludes with North Dakota wheat and Mississippi cotton. Results for each crop-region combination are presented in tabular form. The first numerical column is the value that would be expected for ICM participants in 1990 based upon their pre-ICM levels and statistically significant percentage changes, if any, in the OYS benchmark data from 1989 to 1990. The second column is the actual value in 1990 for ICM participants. This is followed by the

change, the percentage change, and finally the T statistic for significance of the change. At the 95-percent level of significance, a T-statistic of 1.96 or higher in absolute value is considered significant.

Nebraska Corn

No significant yield changes were detected for Nebraska corn growers as a result of ICM. However, both nitrogen and phosphorus use fell significantly for the ICM group (table 1). ICM participants reduced overall nitrogen application by 16 percent, and the average phosphate application rate dropped by nearly 32 percent. ICM participation resulted in no significant change in potash application for Nebraska corn.

The analysis indicates a net 21-percent increase in the total use of herbicides on Nebraska corn on ICM farms relative to the control group.[11] The primary reason for this increase is a 33-percent reduction in alachlor for the control group according to the OYS, but no significant reduction in alachlor for ICM participants resulting in a 59-percent relative increase attributed to ICM participation (app. table 1).

ICM resulted in no significant change in total insecticide use. ICM participants matched the Nebraska control group in the reduction of terbufos, increased the use of carbofuran relative to the control group data by 84 percent, and increased the use of methyl parathion by much less than the control group on a percentage basis.

Table 1--Net effect of ICM on Nebraska corn

Item	1990 ICM expected	1990 ICM actual	Change	Percentage Change	T statistic
	- - - -Bushels/acre-		- - -	Percent	
Yield	164.1	162.0	-2.0	-1.2	-0.74
Fertilizers:		Pounds/acre			
Nitrogen	186.3	155.8	-30.5	-16.4	-6.76
Phosphate	18.4	12.6	-5.8	-31.7	-3.04
Potash	6.2	3.8	-2.4	-38.8	- .99
Herbicides:					
Atrazine	.7625	.8061	.0436	5.7	.78
Alachlor	.2533	.4020	.1487	58.7	3.08
Metolachlor	.3189	.3852	.0664	20.8	1.11
Cyanazine	.0427	.0498	.0070	16.5	.27
Butylate	.0475	.0565	.0089	18.8	.21
2,4-D	.0049	0	- .0049	-100.0	-1.33
Dicamba	.0597	.0400	- .0197	-33.0	-1.23
Total herbicide active ingredients	1.3512	1.6324	.2812	20.8	2.90
Insecticides:					
Terbufos	.2728	.2834	.0106	3.9	.28
Chlorpyrifos	.0987	.0808	- .0179	-18.1	- .80
Carbofuran	.0698	.1282	.0583	83.5	2.71
Fonofos	.0444	.0562	.0117	26.4	.90
Methyl parathion	.5581	.2231	- .3350	-60.0	-7.51
Total insecticide active ingredients	.6510	.7241	.0730	11.2	1.19

[11]Control group herbicide use, measured as total pounds of all active ingredients, fell significantly (-36 percent) for Nebraska corn acres according to the OYS. Average herbicide use also fell significantly for ICM participants, but at a lesser rate (-23 percent). Therefore the net effect of ICM was ((1 - .23) - (1 - .36))/(1 - .36), for a net increase of about 21 percent.

Nebraska Soybeans

Nebraska soybeans grown by ICM participants experienced a statistically significant yield reduction of 17 percent (table 2).

ICM generated no statistically significant net effects on fertilizer use or total herbicide application for Nebraska soybeans. However, ICM adoption led to statistically significant reductions in the individual herbicides chlorimuron and quizalofop-ethyl. In both cases, average uses of these herbicides were reduced to zero. Insecticides are not reported since their use was not widespread on Nebraska soybeans for either ICM participants or for the control group according to the OYS.

Table 2--Net effect of ICM on Nebraska soybeans

Item	1990 ICM expected	1990 ICM actual	Change	Percentage Change	T statistic
	- - - -Bushels/acre-		- - -	Percent	
Yield	44.9	37.4	-7.5	-16.7	-2.35
Fertilizers:		Pounds/acre			
Nitrogen	16.9	16.3	- .5	-3.2	- .05
Phosphate	13.0	19.4	6.4	49.5	.59
Potash	20.5	.1	-20.5	-99.6	- .87
Herbicides:					
Trifluralin	.1407	.0572	- .0835	-59.3	- .90
Pendimethalin	.0232	0	- .0232	-100.0	- .60
Metribuzin	.0030	.0308	.0278	933.8	.77
Clomazone	.0874	.1627	.0753	86.2	.60
Imazaquin	.0019	0	- .0019	-100.0	- .60
Fluazifop-p-butyl	.0011	.0165	.0155	1452.1	1.45
Alachlor	.1058	.1354	.0296	28.0	.29
Propachlor	.2693	.4897	.2204	81.8	1.34
Chlorimuron	.0017	0	- .0017	-100.0	-21.47
EPTC	.0052	.0048	- .0004	-7.2	- .14
Quizalofop-ethyl	.0590	0	- .0590	-100.0	-1.99
Total herbicide active ingredients	.3597	.6389	.2792	77.6	1.78

Iowa Corn

Corn yields rose significantly (9 percent) for the Iowa control group, according to the OYS, but did not change for ICM participants. Therefore,the net yield loss attributed to ICM on Iowa corn was about 7 percent (table 3). ICM had no effect on fertilizer use for Iowa corn.

Total herbicide use on corn for the Iowa control group decreased significantly by 29 percent, but did not change significantly for ICM participants (app. table 3). This situation translated into a net increase in herbicide use of 32 percent due to ICM. Atrazine application by ICM participants increased by 57 percent while decreasing 44 percent for the control group, implying that the net effect of ICM on atrazine use was an increase of 179 percent. However, ICM reduced the application rate of bromoxynil by 49 percent and reduced the use of pendimethalin by 71 percent.

ICM had no significant net effect on the overall application of insecticides on Iowa corn, as measured by total pounds of all active ingredients. However, the application rate of the insecticide chlorpyrifos increased by

434 percent as a result of ICM (51-percent reduction for the control group, 161-percent increase for ICM participants).

Table 3--Net effect of ICM on Iowa corn

Item	1990 ICM expected	1990 ICM actual	Change	Percentage Change	T statistic
	- - - -Bushels/acre-		- - -	Percent	
Yield	136.5	126.8	-9.8	-7.2	-2.80
Fertilizers:		Pounds/acre			
Nitrogen	138.3	134.7	-3.7	-2.6	- .25
Phosphate	57.5	59.1	1.7	2.9	.07
Potash	76.5	75.5	-1.0	-1.3	- .07
Herbicides:					
Atrazine	.2131	.5946	.3814	179.0	3.83
Metolachlor	.7029	.6953	- .0076	-1.1	- .04
Alachlor	.8115	.7147	- .0968	-11.9	- .51
Cyanazine	.4315	.6868	.2552	59.1	1.43
Dicamba	.1437	.1450	.0012	.9	.03
EPTC	.6546	1.1335	.4789	73.2	1.10
2,4-D	.0390	.0582	.0192	49.3	.55
Bromoxynil	.1340	.0680	- .0660	-49.3	-2.77
Pendimethalin	.6454	.1872	- .4582	-71.0	-5.78
Total herbicide active ingredients	3.1944	4.2245	1.0302	32.2	2.11
Insecticides:					
Terbufos	.1633	.2843	.1210	74.1	1.66
Chlorpyrifos	.0253	.1352	.1099	433.6	2.34
Carbofuran	.1134	.0682	- .0453	-39.9	- .89
Total insecticide active ingredients	.3285	.4810	.1525	46.4	1.62

Iowa Soybeans

Iowa soybean yields were not significantly affected by ICM. Further, ICM had no effect on fertilizer use (table 4).

Overall herbicide use was not significantly affected by ICM. However, reductions of application rates for the herbicides imazaquin (98 percent) and fluazifop-p-butyl (91 percent) were statistically significant. The primary insecticide used on Iowa soybeans, carbaryl, was not significantly affected by ICM.

Table 4--Net effect of ICM on Iowa soybeans

Item	1990 ICM expected	1990 ICM actual	Change	Percentage Change	T statistic
	- - - -Bushels/acre- - - -			Percent	
Yield	40.8	42.1	1.3	3.1	0.93
Fertilizers:		Pounds/acre			
Nitrogen	15.3	39.0	23.7	155.2	1.16
Phosphate	20.3	44.3	24.0	118.0	1.88
Potash	78.0	84.0	6.0	7.7	.37
Herbicides:					
Trifluralin	.4973	.5870	.0896	18.0	.63
Metribuzin	.0402	.0672	.0270	67.1	.84
Bentazon	.0880	.1107	.0227	25.8	.37
Clomazone	.0203	.0300	.0097	47.7	.33
Pendimethalin	.2888	.1816	- .1073	-37.1	- .94
Imazethapyr	0	0	0	NA89	NA89
Alachlor	.0327	0	- .0327	-100.0	- .65
Chlorimuron	.0002	.0003	0	7.1	.10
Acifluorfen	.0077	.0153	.0077	100.1	.41
Ethalfluralin	0	0	.0000	NA89	NA89
Imazaquin	.0500	.0010	- .0490	-98.0	-4.49
Thiameturon-methyl	0	0	0	NA89	NA89
Fluazifop-p-butyl	.1579	.0140	- .1438	-91.1	-22.54
Propachlor	.2140	.1318	- .0822	-38.4	- .79
Quizalofop-ethyl	.0041	.0126	.0084	203.9	1.06
Total herbicide active ingredients	1.1317	1.0790	- .0527	-4.7	- .29
Insecticides:					
Carbaryl	0.8246	0	- .8246	-100.0	-1.77

NA89 = Not applied in 1989.

North Dakota Wheat

The measured net effect of ICM on North Dakota wheat yield was a 51-percent reduction (table 5). This drop resulted from a statistically significant 53-percent increase in yield for the North Dakota control group between 1989 and 1990, and a statistically significant 25-percent reduction in ICM participant's wheat yield (table 5). However, the magnitude of this effect is likely due to low (50 percent) reporting of ICM wheat yields.

ICM had a significant effect on nitrogen use, producing a 32-percent reduction. However, ICM did not significantly affect phosphate and potash application rates.

Although control group herbicide use rose, it fell for ICM participants, resulting in a 39-percent reduction attributable to ICM. Significant reductions in individual herbicides were found for MCPA (79 percent) and trifluralin (86 percent), while application of imidazolinone by ICM participants went from zero to 0.0378 pound for the average acre. Insecticides were not reported because their use was not widespread for either ICM participants or the control group, according to the OYS.

Table 5--Net effect of ICM on North Dakota wheat

Item	1990 ICM expected	1990 ICM actual	Change	Percentage Change	T statistic
	- - - -Bushels/acre-		- - -	Percent	
Yield	79.0	38.9	-40.1	-50.8	-17.09
Fertilizers:		Pounds/acre			
Nitrogen	82.4	56.4	-26.0	-31.6	-2.91
Phosphate	33.7	28.7	-5.0	-14.8	-1.83
Potash	5.0	3.7	-1.3	-26.7	-1.15
Herbicides:					
2,4-D	.1241	.0853	- .0388	-31.2	- .71
MCPA	.4144	.0886	- .3258	-78.6	-8.78
Dicamba	.0499	.0068	- .0431	-86.4	-11.74
Trifluralin	.0126	.0075	- .0051	-40.5	- .45
Diclofop-methyl	.0256	.0353	.0097	37.9	.20
DPX-L5300	.0001	.0011	.0010	814.1	1.49
DPX-M6316	.0001	.0021	.0021	3,543.7	1.62
Imidazolinone	0	.0378	.0378	NA89	4.07
Total herbicide active ingredients	.3988	.2430	- .1558	-39.1	-2.06

NA89 = Not applied in 1989.

Mississippi Cotton

Due to a low level of 1990 ICM cotton yield reporting, the effect of ICM on Mississippi cotton output could not be determined (table 6). Because insecticide use data were not collected for cotton in the 1990 Cropping Practices Survey and herbicide use on cotton was minimal, the only tests that could be applied to Mississippi cotton were for potential changes in fertilizer use.

Average nitrogen application rates declined by 21 percent due to ICM participation (table 6). Phosphate and potash use was not significantly affected.

Table 6--Net effect of ICM on Mississippi cotton

Fertilizer	1990 ICM expected	1990 ICM actual	Change	Percentage Change	T statistic
	- - - Pounds/acre - - -			Percent	
Nitrogen	116.6	92.6	-24.0	-20.6	-3.87
Phosphate	36.9	35.6	-1.3	-3.5	- .26
Potash	61.6	52.9	-8.7	-14.1	-1.27

Summary of ICM Effects

Our analysis suggests that in its first year, ICM's effect on crop yields was insignificant to slightly negative (table 7). The largest negative effect (51 percent on North Dakota wheat yields) may be partially due to incomplete ICM reporting.

With respect to fertilizer use, ICM seemed to be most effective in reducing nitrogen application rates. Because nitrogen is applied at relatively low rates on soybeans, one would not expect large reductions for this crop. For the remaining crop-region combinations, except Iowa corn, nitrogen was reduced by 16 to 32 percent. ICM resulted in a phosphate reduction only for corn in Nebraska. In all other instances, ICM had no effect on phosphate or potash application rates.

The effect of ICM on total herbicide application appears to vary by crop. For Nebraska and Iowa corn, ICM participation was associated with a net increase in total herbicide application rates. For Nebraska and Iowa soybeans, ICM had no significant effect. For North Dakota wheat, ICM decreased total herbicide application.

The results of ICM on total insecticide application rates are restricted to Nebraska and Iowa corn. In both cases, ICM had no significant effect.

Table 7--Summary of ICM yield and input changes by State and crop

State/crop	Yield	Nitrogen	Phosphate	Potash	Herbicides	Insecticides
			Percent			
Nebraska corn	NE	-16	-31	NE	21	NE
Nebraska soybeans	-17	NE	NE	NE	NE	NU
Iowa corn	-7	NE	NE	NE	31	NE
Iowa soybeans	NE	NE	NE	NE	NE	NU
North Dakota wheat	-51	-32	NE	NE	-39	NU
Mississippi cotton	?	-21	NE	NE	NU	?

NE = No statistically significant net effect.
NU = Not used to any great extent in this area on this crop; no test.
? = Missing data; not able to test difference.

Sensitivity of Results to Control Group Comparisons

Crop-specific control group yield and chemical use rates were calculated as State-level averages from the OYS. However, counties participating in ICM often were not distributed uniformly throughout a State. In Nebraska, for instance, the counties approved to participate in ICM tended to be clustered in the south-central portion of the State. Thus, the previous ICM results could be biased by comparing ICM farmers in selected counties with overgeneralized Statewide averages. An alternative is to calculate control group average yield and chemical use rates from only the OYS observations located in ICM-approved counties (restricted control group). This approach may provide greater confidence about similarity of weather patterns, soil types, and institutional structures, but this gain comes at the expense of dramatically fewer observations in the control group. For example, in the analysis of Iowa corn, 410 observations were available from the OYS at the State level, but only 15 were located in ICM-approved counties. Table 8 shows the number of observations for each State-crop combination for ICM program participants and for control groups at the State level and within ICM-approved counties.

Despite the loss of observations in the restricted control group, we recomputed the hypothesis tests to determine if the original results would be affected. Retesting the hypotheses with the restricted control group produces some changes relative to the results presented in table 7. Herbicide use was the category most changed by using the restricted control group. However, where changes occurred, they were not consistently in the direction of less chemical use or more chemical use. Using the restricted control group, the yield effect on Iowa corn changes from a 7-percent decrease (table 7) to no effect attributable to ICM. The yield effect for North Dakota wheat also changes from a 51-percent decrease to a 38-percent decrease.

Phosphate use on North Dakota wheat changes from no effect under the State-level control group to a 56-percent net increase under the control group restricted to ICM-approved counties. Herbicide use for ICM

farmers in Nebraska goes from an increase of 21 percent to no net effect when the restricted control group is used. Herbicide use on Iowa corn goes from a 32-percent increase to no net effect. Finally, herbicide use on North Dakota wheat goes from a 39-percent decrease to no net effect.

Table 8--Number of observations for ICM program participants, State-level control group, and control group restricted to ICM-approved counties

State/crop	ICM program participants	OYS State-level control group	OYS control group restricted to ICM-approved counties
		Number	
Nebraska Corn	378	196	39
Nebraska Soybeans	32	85	4
Iowa Corn	75	410	15
Iowa Soybeans	42	375	18
North Dakota Wheat	128	245	20
Mississippi Cotton	100	161	14

Leaching and Runoff Potential

Besides changes in the amounts of pesticide active ingredient applied to cropland, water quality concerns must also focus on the runoff or leaching potential of the chemicals used. If the overall quantity of pesticides is reduced, yet more leachable pesticides or those with higher runoff characteristics are substituted, then the overall benefits to the environment are unclear. Although the primary focus of the ICM program was clearly on reducing the volume of pesticides used, program guidelines encouraged the substitution of more environmentally acceptable pesticides with lower toxicity, shorter half-lives, reduced leachability, or reduced host resistance. Program guidelines further specified that "no practice may be approved on the basis of reducing the volume of pesticides or nutrients used, when this is achieved solely by substituting more toxic or persistent pesticides."

We used a procedure developed by the Soil Conservation Service to assess changes in the potential for runoff to surface water and leaching to groundwater for pesticides applied on ICM fields. The screening procedure evaluates the relative potential loss of specific pesticides from soils and is based on numerous simulations using the GLEAMS model. Estimated pesticide losses are categorized into leaching, adsorbed runoff, and solution runoff. Potentials are identified as small, medium, and large.

To assess the ICM program, we assigned the total amount of insecticide and herbicide active ingredients for the "average" field into each potential loss category for 1989 (pre-ICM) and 1990 (ICM) (tables 9 and 10). Unlike the previous analyses, this assessment looked at pesticide use before and after ICM implementation as opposed to with and without. If the percentage of total active ingredients in the small category decreases and the percentages in the medium and/or large categories increase, then the potential for runoff or leaching is greater. Reverse this and the potential for runoff or leaching decreases.

Separate analyses were conducted for ground water and surface water, because the leaching and runoff potentials for specific active ingredients often differ. As evaluated, the potential for leaching is based on the mix of chemicals applied. Whether the potential is realized depends on the actual amounts applied, specific soil characteristics of ICM fields, and proximity to ground or surface water.

Table 9--Pesticide active ingredient percentages by leaching potential to ground water, by State and crop

State/crop	1989 Pre-ICM leaching potential			1990 ICM leaching potential		
	Small	Medium	Large	Small	Medium	Large
			Percent			
Nebraska corn	22.7	16.1	61.2	27.9	18.0	54.1
Nebraska soybeans	63.1	36.2	.7	63.3	33.2	3.4
Iowa corn	24.6	55.4	20.0	37.9	43.1	19.0
Iowa soybeans	83.4	4.3	12.3	79.4	5.0	15.6
North Dakota wheat	55.2	41.1	3.7	31.2	63.8	5.0

Table 10--Pesticide active ingredient percentages by runoff potential to surface water, by State and crop

State/crop	1989 Pre-ICM runoff potential			1990 ICM runoff potential		
	Small	Medium	Large	Small	Medium	Large
			Percent			
Nebraska corn	0	62.1	37.9	0	65.6	34.4
Nebraska soybeans	0	68.0	32.0	0	93.6	6.4
Iowa corn	0	96.3	3.7	0	93.6	6.4
Iowa soybeans	0	64.1	35.9	0	32.2	67.8
North Dakota wheat	0	88.0	12.0	0	94.5	5.5

Based solely on observing movements between the small, medium, and large categories and not any formal statistical test, the change in the mix of pesticides brought about by ICM may have greater potential for leaching into ground water for North Dakota wheat, Nebraska soybeans, and Iowa soybeans. The potential for leaching to ground water appears to have been reduced for Nebraska corn and Iowa corn.

For surface water, the change in the mix of pesticides associated with ICM participation apparently reduced the potential for runoff for North Dakota wheat, Nebraska corn, and Nebraska soybeans. The potential for runoff appears to have been increased for Iowa corn and Iowa soybeans.

Review of Farmer Comments

Farmers' opinions regarding ICM, while not formally testable, were available in part as written comments. Their remarks suggest that the ICM program was successful and well received by farmers. Many farmers claimed pesticide or fertilizer reductions of at least 20 percent, with a few purporting complete elimination of pesticide use for the first year of ICM. Some participants cited significant cost savings, and one praised the program for allowing him to more accurately determine his fields' fertilizer requirements from year to year. Another, who reported fertilizer savings of up to 80 percent, called ICM an exciting new way of farming.

Regional Differences in ICM

In most counties, ICM plans appear to have been developed by the same individual or organization because plans often varied little. Thus, some counties may have more success with the program than others, based on the potential variation in the quality of the available assistance. ICM plans often varied greatly between counties, perhaps reflecting considerable flexibility in the ways that reductions can be achieved and variation in geographic characteristics and ICM skills.

No regional, multi-State pattern associated with the use of different fertilizer management practices surfaced. Some States focused on the reduction and substitution of fertilizers. Maine cited frequent substitutions of cow manure instead of poultry manure because of the lower concentration of nitrates in cow manure. Michigan reported reductions of nitrogen, phosphate, and potash for each farm but reported only that pesticides had been applied according to labeled directions. Mississippi and Nebraska farmers cited large reductions in fertilizer use, especially nitrogen. Soil testing was almost universal but may not have allowed for significant reductions in Pennsylvania, Virginia, and West Virginia.

The Corn Belt, Southeast, and Delta States typically have greater pest and disease problems than the rest of the country. Thus, the majority of the ICM plans in these areas included pest scouting services with the anticipation that this might allow for reduced pesticide applications. ICM plans in North Dakota frequently involved rental equipment for banded and spot spraying and substitutions among herbicides.

Cropland Management under ICM

Comments indicated that the timing of chemical applications was sometimes changed to reduce the potential for leaching. In some cases, the total quantity in pounds or active ingredients did not fall, but was split across time periods. Farmers in Clinton County, Iowa, reported using no-till and minimum-till practices.

North Dakota, Pennsylvania, Nebraska, and Virginia reported using crop rotations to reduce fertilizer and pesticide requirements. Farmers in North Dakota, Pennsylvania, Illinois, and Iowa used additional cultivations as a substitute for herbicides. However, information on timing, method of application or tillage, or erosion rates that would permit analysis of such management changes was not collected.

Non-ICM Factors

Some farmers in Madison County, Mississippi, expressed the belief that ICM was not responsible for reductions in insecticides used on their fields during 1990. They cited fewer insects that year as the sole reason for the reductions.

Grand Forks and Walsh Counties, North Dakota, experienced 2 consecutive years of severe drought and exceptionally high temperatures. These weather conditions lowered yields and allowed for a high rate of nitrogen carryover into the first program year. Drought conditions affecting preplan yields were also cited frequently by farmers in Pennsylvania, Maryland, and Illinois.

Farmers in several States reported that 1990 fertilizers had been applied before the announcement of the ICM practice. Thus, fertilizer savings may not be realized until the second year of ICM adoption.

Summary

The integrated crop management (ICM) practice, also known as special practice 53 (SP-53), was instituted on a trial basis in 1990 under the Agricultural Conservation Program. The Agricultural Stabilization and Conservation Service administers the program, which provides cost sharing to encourage farmers to adopt systems incorporating integrated pest management and nutrient management practices. Analysis of the first year of ICM, based on a sample of four crops grown in four States, indicates some limited success. The primary effect of ICM appears to have been reduced nitrogen fertilizer use. Use of other fertilizers and pesticides, however, remained generally unaffected. ICM had little or no effect on crop yields. Leaching and runoff potential for pesticides was apparently reduced in some instances, while in others it was increased.

The primary effect of ICM was a reduction of 16 to 32 percent in the application of nitrogen fertilizer on crops such as corn, wheat, and cotton. Use of other fertilizers and insecticides remained generally unaffected.

ICM's effect on herbicide use tended to vary by crop. ICM resulted in a net increase in total herbicide use on corn. ICM had no significant effect on herbicide use on soybeans. Herbicide use on wheat dropped with ICM. When a less general control group with significantly fewer observations was employed, however, herbicide use was unaffected by ICM.

ICM reduced crop yields little, if any. Because of the voluntary nature of the program, farmers who anticipated significant yield reductions would have been unlikely to participate.

Because ICM data were limited to crops grown and amounts of fertilizers and pesticides used, the effects of ICM on farm profitability were not investigated, nor were its effects on environmental quality. Based on an examination of the leaching and runoff characteristics of the pesticides used before and after ICM implementation, we concluded that leaching or runoff potential was reduced in some instances, while it was increased in others.

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Appendix A:
Sequential Hypothesis Test Results

Appendix table 1--Nebraska corn

Item	Objective Yield Survey 1989 mean	1990 mean	Change	Percentage Change	T statistic	ICM participants 1989 mean	1990 mean	Change	Percentage Change	T statistic	Net effect of ICM 1990 expected	1990 ICM	Change	Percentage Change	T statistic
	- - - Bushels/acre - - -			Percent		- - - Bushels/acre - - -			Percent		- - - Bushels/acre - - -			Percent	
Yield	127.8	135.1	7.3	5.7	1.79	164.1	162.0	-2.0	-1.2	- .74	164.1	162.0	-2.0	-1.2	-0.74
Fertilizers:	- - - Pounds/acre - - -			Percent		- - - Pounds/acre - - -			Percent		- - - Pounds/acre - - -			Percent	
Nitrogen	148.6	149.5	.9	.6	.15	186.3	155.8	-30.5	-16.4	-6.76	186.3	155.8	-30.5	-16.4	-6.76
Phosphate	24.9	22.8	-2.1	-8.4	- .95	18.4	12.6	-5.8	-31.7	-3.04	18.4	12.6	-5.8	-31.7	-3.04
Potash	7.0	7.7	.7	10.2	.45	6.2	3.8	-2.4	-38.8	- .99	6.2	3.8	-2.4	-38.8	- .99
Herbicides:															
Atrazine	1.3555	.9648	- .3906	-28.8	-4.47	1.0712	.8061	- .2651	-24.7	-4.76	.7625	.8061	.0436	5.7	.78
Alachlor	.8619	.5742	- .2877	-33.4	-2.69	.3803	.4020	.0217	5.7	.45	.2533	.4020	.1487	58.7	3.08
Metolachlor	.4698	.2466	- .2232	-47.5	-2.86	.6075	.3852	- .2223	-36.6	-3.73	.3189	.3852	.0664	20.8	1.11
Cyanazine	.4785	.2261	- .2524	-52.7	-2.89	.0904	.0498	- .0407	-45.0	-1.57	.0427	.0498	.0070	16.5	.27
Butylate	.4518	.3041	- .1478	-32.7	-1.18	.0475	.0565	.0089	18.8	.21	.0475	.0565	.0089	18.8	.21
2,4-d	.0958	.0745	- .0213	-22.2	- .61	.0049	0	- .0049	-100.0	-1.33	.0049	0	- .0049	-100.0	-1.33
Dicamba	.0309	.0419	.0110	35.6	.72	.0597	.0400	- .0197	-33.0	-1.23	.0597	.0400	- .0197	-33.0	-1.23
Total herbicide active ingredients	3.7114	2.3615	-1.3500	-36.4	-8.03	2.1237	1.6324	- .4913	-23.1	-5.06	1.3512	1.6324	.2812	20.8	2.90
Insecticides:															
Terbufos	.4244	.3013	- .1230	-29.0	-2.03	.3842	.2834	- .1008	-26.2	-2.67	.2728	.2834	.0106	3.9	.28
Chlorpyrifos	.2038	.1596	- .0441	-21.7	- .81	.0987	.0808	- .0179	-18.1	- .80	.0987	.0808	- .0179	-18.1	- .80
Carbofuran	.0682	.0588	- .0094	-13.7	- .42	.0698	.1282	.0583	83.5	2.71	.0698	.1282	.0583	83.5	2.71
Fonofos	.0540	.0586	.0046	8.5	.17	.0444	.0562	.0117	26.4	.90	.0444	.0562	.0117	26.4	.90
Methyl parathion	.0082	.0475	.0393	480.7	2.90	.0961	.2231	.1270	132.1	2.84	.5581	.2231	- .3350	-60.0	-7.51
Total insecticide active ingredients	.7519	.6077	- .1442	-19.2	-1.89	.6510	.7241	.0730	11.2	1.19	.6510	.7241	.0730	11.2	1.19

Appendix table 2--Nebraska soybeans

Item	Objective Yield Survey 1989 mean	1990 mean	Change	Percentage Change	T statistic	ICM participants 1989 mean	1990 mean	Change	Percentage Change	T statistic	Net effect of ICM 1990 expected	1990 ICM	Change	Percentage Change	T statistic
	- - - Bushels/acre- - -			Percent		- - - Bushels/acre- - -			Percent		- - - Bushels/acre- - -			Percent	
Yield	30.8	33.2	2.4	7.8	1.30	44.9	37.4	-7.5	-16.7	-2.35	44.9	37.4	-7.5	-16.7	-2.35
Fertilizers:	- - - Pounds/acre - - -			Percent		- - - Pounds/acre - - -			Percent		- - - Pounds/acre - - -			Percent	
Nitrogen	3.7	4.8	1.2	32.3	.50	16.9	16.3	- .5	-3.2	- .05	16.9	16.3	- .5	-3.2	- .05
Phosphate	10.0	4.7	-5.3	-53.2	-2.05	27.8	19.4	-8.3	-30.0	- .76	13.0	19.4	6.4	49.5	.59
Potash	2.9	1.5	-1.4	-49.0	-1.13	20.5	.1	-20.5	-99.6	- .87	20.5	.1	-20.5	-99.6	- .87
Herbicides:															
Trifluralin	.3293	.4072	.0780	23.7	1.22	.1407	.0572	- .0835	-59.3	- .90	.1407	.0572	- .0835	-59.3	- .90
Pendimethalin	.2424	.1529	- .0895	-36.9	-1.39	.0232	0	- .0232	-100.0	- .60	.0232	0	- .0232	-100.0	- .60
Imazethapyr	.0121	.0501	.0380	313.3	2.41	0	0	0	NA89	NA90	0	0	0	NA89	NA90
Metribuzin	.1098	.0938	- .0160	-14.5	- .41	.0030	.0308	.0278	933.8	.77	.0030	.0308	.0278	933.8	.77
Clomazone	.1829	.1124	- .0705	-38.5	-1.34	.0874	.1627	.0753	86.2	.60	.0874	.1627	.0753	86.2	.60
Imazaquin	.0183	.0254	.0071	39.1	.57	.0019	0	- .0019	-100.0	- .60	.0019	0	- .0019	-100.0	- .60
Bentazon	.1006	.0317	- .0689	-68.5	-2.10	0	0	0	NA89	NA90	0	0	0	NA89	NA90
Fluazifop-p-butyl	.0257	.0183	- .0074	-28.9	- .37	.0011	.0165	.0155	1452.1	1.45	.0011	.0165	.0155	1452.1	1.45
Alachlor	.2012	.1360	- .0652	-32.4	- .70	.1058	.1354	.0296	28.0	.29	.1058	.1354	.0296	28.0	.29
Propachlor	.1098	.0220	- .0878	-80.0	-1.12	.2693	.4897	.2204	81.8	1.34	.2693	.4897	.2204	81.8	1.34
Chlorimuron	.0002	.0037	.0035	1412.1	2.91	.0001	0	- .0001	-100.0	-1.42	.0017	0	- .0017	-100.0	-21.47
Eptc	0	0	0	NA89	NA90	.0052	.0048	- .0004	-7.2	- .14	.0052	.0048	- .0004	-7.2	- .14
Quizalofop-ethyl	0	0	0	NA89	NA90	.0590	0	- .0590	-100.0	-1.99	.0590	0	- .0590	-100.0	-1.99
Total herbicide active ingredients	1.2853	1.0046	- .2807	-21.8	-2.33	.4603	.6389	.1787	38.8	1.14	.3597	.6389	.2792	77.6	1.78

NA89 = Not applied in 1989.
NA90 = Not applied in 1990.

Appendix table 3--Iowa corn

Item	Objective Yield Survey					ICM participants					Net effect of ICM				
	1989 mean	1990 mean	Change	Percentage Change	T statistic	1989 mean	1990 mean	Change	Percentage Change	T statistic	1990 expected	1990 ICM	Change	Percentage Change	T statistic
	- - - Bushels/acre - - -			Percent		- - - Bushels/acre - - -			Percent		- - - Bushels/acre - - -			Percent	
Yield	118.8	129.8	11.0	9.2	2.69	125.0	126.8	1.8	1.4	0.50	136.5	126.8	-9.8	-7.2	-2.80
Fertilizers:	- - - Pounds/acre - - -			Percent		- - - Pounds/acre - - -			Percent		- - - Pounds/acre - - -			Percent	
Nitrogen	126.9	121.8	-5.1	-4.0	-1.19	138.3	134.7	-3.7	-2.6	- .25	138.3	134.7	-3.7	-2.6	- .25
Phosphate	49.0	47.7	-1.2	-2.5	- .47	57.5	59.1	1.7	2.9	.07	57.5	59.1	1.7	2.9	.07
Potash	57.2	59.4	2.2	3.9	.64	76.5	75.5	-1.0	-1.3	- .07	76.5	75.5	-1.0	-1.3	- .07
Herbicides:															
Atrazine	.9944	.5582	- .4362	-43.9	-6.07	.3797	.5946	.2149	56.6	2.16	.2131	.5946	.3814	179.0	3.83
Metolachlor	.6454	.7990	.1536	23.8	1.90	.7029	.6953	- .0076	-1.1	- .04	.7029	.6953	- .0076	-1.1	- .04
Alachlor	.7593	.4925	- .2669	-35.1	-2.96	1.2513	.7147	- .5366	-42.9	-2.81	.8115	.7147	- .0968	-11.9	- .51
Cyanazine	.7949	.3665	- .4284	-53.9	-4.62	.9359	.6868	- .2491	-26.6	-1.40	.4315	.6868	.2552	59.1	1.43
Dicamba	.0841	.0860	.0019	2.3	.13	.1437	.1450	.0012	.9	.03	.1437	.1450	.0012	.9	.03
EPTC	.8037	.6416	- .1622	-20.2	-1.28	.6546	1.1335	.4789	73.2	1.10	.6546	1.1335	.4789	73.2	1.10
2,4-D	.1682	.0700	- .0982	-58.4	-3.52	.0937	.0582	- .0355	-37.9	-1.02	.0390	.0582	.0192	49.3	.55
Bromoxynil	.0438	.0587	.0149	34.1	1.36	.1340	.0680	- .0660	-49.3	-2.77	.1340	.0680	- .0660	-49.3	-2.77
Pendimethalin	.0129	.0465	.0336	261.9	2.48	.1783	.1872	.0088	5.0	.11	.6454	.1872	- .4582	-71.0	-5.78
Total herbicide active ingredients	4.2278	3.0184	-1.2093	-28.6	-8.48	4.4742	4.2245	- .2497	-5.6	- .51	3.1944	4.2245	1.0302	32.2	2.11
Insecticides--															
Terbufos	.1822	.1895	.0073	4.0	.19	.1633	.2843	.1210	74.1	1.66	.1633	.2843	.1210	74.1	1.66
Chlorpyrifos	.1717	.0840	- .0877	-51.1	-2.33	.0518	.1352	.0834	161.1	1.78	.0253	.1352	.1099	433.6	2.34
Carbofuran	.0105	.0140	.0035	33.4	.44	.1134	.0682	- .0453	-39.9	- .89	.1134	.0682	- .0453	-39.9	- .89
Total insecticide active ingredients	.3578	.2783	- .0795	-22.2	-1.61	.3285	.4810	.1525	46.4	1.62	.3285	.4810	.1525	46.4	1.62

Appendix table 4--Iowa soybeans

Item	Objective Yield Survey 1989 mean	1990 mean	Change	Percentage Change	T statistic	ICM participants 1989 mean	1990 mean	Change	Percentage Change	T statistic	Net effect of ICM 1990 expected	1990 ICM	Change	Percentage Change	T statistic
	- - - Bushels/acre- - -			Percent		- - - Bushels/acre- - -			Percent		- - - Bushels/acre- - -			Percent	
Yield	38.6	40.2	1.7	4.3	1.14	40.8	42.1	1.3	3.1	0.93	40.8	42.1	1.3	3.1	.93
Fertilizers:	- - - Pounds/acre - - -			Percent		- - - Pounds/acre - - -			Percent		- - - Pounds/acre - - -			Percent	
Nitrogen	1.4	3.3	1.9	135.9	2.21	6.5	39.0	32.5	502.1	1.59	15.3	39.0	23.7	155.2	1.16
Phosphate	8.2	4.8	-3.4	-41.2	-1.86	20.3	44.3	24.0	118.0	1.88	20.3	44.3	24.0	118.0	1.88
Potash	12.0	7.7	-4.3	-35.6	-1.54	78.0	84.0	6.0	7.7	.37	78.0	84.0	6.0	7.7	.37
Herbicides:															
Trifluralin	.4745	.5378	.0633	13.3	1.43	.4973	.5870	.0896	18.0	.63	.4973	.5870	.0896	18.0	.63
Metribuzin	.1378	.0419	- .0958	-69.6	-4.47	.1322	.0672	- .0649	-49.1	-2.02	.0402	.0672	.0270	67.1	.84
Bentazon	.1786	.1379	- .0407	-22.8	-1.34	.0880	.1107	.0227	25.8	.37	.0880	.1107	.0227	25.8	.37
Clomazone	.1905	.1059	- .0846	-44.4	-2.37	.0366	.0300	- .0066	-17.9	- .22	.0203	.0300	.0097	47.7	.33
Pendimethalin	.1403	.1053	- .0350	-24.9	-1.06	.2888	.1816	- .1073	-37.1	- .94	.2888	.1816	- .1073	-37.1	- .94
Imazethapyr	.0072	.0756	.0684	956.8	9.85	0	0	0	NA89	NA90	0	0	0	NA89	NA90
Alachlor	.2993	.1809	- .1184	-39.6	-1.58	.0327	0	- .0327	-100.0	- .65	.0327	0	- .0327	-100.0	- .65
Chlorimuron	.0008	.0020	.0012	160.2	3.45	.0001	.0003	.0002	178.6	.96	.0002	.0003	0	7.1	.10
Acifluorfen	.0374	.0129	- .0245	-65.6	-2.03	.0223	.0153	- .0069	-31.1	- .37	.0077	.0153	.0077	100.1	.41
Ethalfluralin	.0602	.0895	.0292	48.6	1.30	0	0	0	NA89	NA90	0	0	0	NA89	NA90
Imazaquin	.0026	.0015	- .0010	-39.7	- .62	.0500	.0010	- .0490	-98.0	-4.49	.0500	.0010	- .0490	-98.0	-4.49
Thiameturon-methyl	0	.0004	.0004	813.6	6.25	0	0	0	NA89	NA90	0	0	0	NA89	NA90
Fluazifop-p-butyl	.0016	.0250	.0234	1464.5	3.87	.0101	.0140	.0039	38.8	.61	.1579	.0140	- .1438	-91.1	-22.54
Propachlor	.0306	.0085	- .0221	-72.3	- .71	.2140	.1318	- .0822	-38.4	- .79	.2140	.1318	- .0822	-38.4	- .79
Quizalofop-ethyl	0	.0226	.0226	NA89	5.15	.0041	.0126	.0084	203.9	1.06	.0041	.0126	.0084	203.9	1.06
Total herbicide active ingredients	1.5507	1.3185	- .2322	-15.0	-2.56	1.3309	1.0790	- .2519	-18.9	-1.39	1.1317	1.0790	- .0527	-4.7	- .29
Insecticides:															
Carbaryl	0	0	0	NA89	NA90	.8246	0	- .8246	-100.0	-1.77	.8246	0	- .8246	-100.0	-1.77

NA89 = Not applied in 1989.
NA90 = Not applied in 1990.

Appendix table 5--North Dakota wheat

Item	Objective Yield Survey					ICM participants					Net effect of ICM				
	1989 mean	1990 mean	Change	Percentage Change	T statistic	1989 mean	1990 mean	Change	Percentage Change	T statistic	1990 expected	1990 ICM	Change	Percentage Change	T statistic
	- - - Bushels/acre- - -			Percent		- - - Bushels/acre- - -			Percent		- - - Bushels/acre- - -			Percent	
Yield	24.1	36.8	12.7	52.6	10.22	51.8	38.9	-12.9	-24.9	-5.50	79.0	38.9	-40.1	-50.8	-17.09
Fertilizers:	- - - Pounds/acre - - -			Percent		- - - Pounds/acre - - -			Percent		- - - Pounds/acre - - -			Percent	
Nitrogen	29.7	27.4	-2.3	-7.6	- .73	82.4	56.4	-26.0	-31.6	-2.91	82.4	56.4	-26.0	-31.6	-2.91
Phosphate	17.0	17.6	.6	3.6	.27	33.7	28.7	-5.0	-14.8	-1.83	33.7	28.7	-5.0	-14.8	-1.83
Potash	1.6	1.9	.3	21.5	.60	5.0	3.7	-1.3	-26.7	-1.15	5.0	3.7	-1.3	-26.7	-1.15
Herbicides:															
2,4-D	.2638	.3846	.1208	45.8	2.72	.0851	.0853	.0002	.2	.00	.1241	.0853	- .0388	-31.2	- .71
MCPA	.1020	.2369	.1349	132.3	3.57	.1784	.0886	- .0898	-50.3	-2.42	.4144	.0886	- .3258	-78.6	-8.78
Dicamba	.0250	.1583	.1333	533.7	6.01	.0079	.0068	- .0011	-13.9	- .30	.0499	.0068	- .0431	-86.4	-11.74
Trifluralin	.1728	.0857	- .0871	-50.4	-3.13	.0255	.0075	- .0180	-70.5	-1.58	.0126	.0075	- .0051	-40.5	- .45
Diclofop-methyl	.1144	.0318	- .0826	-72.2	-3.55	.0919	.0353	- .0566	-61.6	-1.19	.0256	.0353	.0097	37.9	.20
DPX-L5300	.0115	.0012	- .0104	-90.0	-4.39	.0012	.0011	- .0001	-8.2	- .15	.0001	.0011	.0010	814.1	1.49
DPX-M6316	.0231	.0006	- .0225	-97.5	-4.77	.0023	.0021	- .0002	-8.2	- .15	.0001	.0021	.0021	3543.7	1.62
Imidazolinone	0	.0051	.0051	NA89	1.91	0	.0378	.0378	NA89	4.07	0	.0378	.0378	NA89	4.07
Total herbicide active ingredients	.6728	.8299	.1571	23.3	2.45	.3233	.2430	- .0803	-24.8	-1.06	.3988	.2430	- .1558	-39.1	-2.06

NA89 = Not applied in 1989.
NA90 = Not applied in 1990.

Appendix table 6--Mississippi cotton

Item	Objective Yield Survey					ICM participants					Net effect of ICM				
	1989 mean	1990 mean	Change	Percentage Change	T statistic	1989 mean	1990 mean	Change	Percentage Change	T statistic	1990 expected	1990 ICM	Change	Percentage Change	T statistic
Fertilizers:	- - - Pounds/acre - - -			Percent		- - - Pounds/acre - - -			Percent		- - - Pounds/acre - - -			Percent	
Nitrogen	103.1	108.7	5.6	5.4	1.24	116.6	92.6	-24.0	-20.6	-3.87	116.6	92.6	-24.0	-20.6	-3.87
Phosphate	26.8	21.3	-5.5	-20.5	-1.76	36.9	35.6	-1.3	-3.5	- .26	36.9	35.6	-1.3	-3.5	- .26
Potash	39.6	44.1	4.5	11.3	.91	61.6	52.9	-8.7	-14.1	-1.27	61.6	52.9	-8.7	-14.1	-1.27

Appendix B:
Economic Modeling of ICM

To understand all the effects of ICM, one might wish to consider the complete economy. Maximization of social welfare would involve choices of both goods and unpriced environmental amenities. Choices would be subject to income and resource availability constraints. Income, which comes from returns to owned factors of production, will change with changes in the ICM subsidy. A welfare function would describe the optimal choice of goods and provide a measure of environmental benefits.

Out of society's welfare maximization problem would come the demand for goods and the supply of factor services: labor, land, and capital. The graphical model shows the household, whose goal is maximizing welfare, and the linkages in the economy that we might wish to include in a whole-economy model. The farm sector is shown using intermediate inputs from two types of suppliers, the intensive-chemical input suppliers and the alternative (such as scouting services) input suppliers. The farm may be seen as substituting input use from one type of input to another.[1]

Looking at the total economy, there are several questions we might wish to answer about the effects of ICM:

1. What are the changes in income for society as a whole?
2. What are the changes in society's welfare?
3. What are the differential effects on farm input suppliers?
4. What are the effects on the environment, and what are their consequences in welfare terms?
5. What is the change in resource use and values?
6. What changes occur in farm input use (or technology)?
7. What are the changes in farm goods supplied and their prices?

While a general equilibrium model may be the most rigorous means of analyzing the effects of Government policies, formulating such a model in sufficient detail to capture the limited effects of the ICM program would be difficult. Instead, some form of partial equilibrium model would probably be sufficient to capture the effects of ICM. Considering the above seven points, we can draw the following conclusions:

1. Although differential effects may be substantial to certain input suppliers, overall income should change very little from ICM. Therefore, the income feedback to agricultural demand is almost certainly not worth modeling.

2. Society's welfare can be affected by changes in the supply of goods, changes in demand through income, or changes in the environment. Because income changes little, we can focus attention on the changes in farm goods supplied and the amounts of environmental goods available.

3. If supplies remain fairly constant, the effects of ICM changes on input suppliers can be determined from the changes in quantities of various inputs demanded by the farm sector.

4. Effects on the environment can be calculated from farm input use and output changes.

5. The change in resource use can also be determined from changes in farm inputs demanded.

6. The change in overall farm input use can be determined from changes in farm inputs demanded.

7. Changes in farm outputs supplied can be determined from a farm-only model.

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[1]The farm can be seen as switching from one production technology to another, where a given production technology is described by the types of physical inputs used and practices adopted.

In conclusion, a partial equilibrium model that focuses on changes in farm outputs, changes in agricultural inputs, and changes in environmental effect should serve as well as a more elaborate model in measuring the effects of the ICM program. If we adopt some reasonable assumptions, we can show that a cost-benefit model can capture the effects of the ICM. Such an analysis would recognize explicitly that widespread adoption of ICM would significantly change environmental quality. Thus, cost-benefit analysis of an expanded ICM program requires information on the social cost of the policy and some monetary measure of the benefit from improvements in environmental quality.

The scale of the ICM program influences the type of analysis attempted. If the ICM is meant to be a demonstration project, the need for analysis is based on helping farmers understand the implications of the program, and cost-benefit analysis need not be attempted. One approach would be to publish the data, either in total or in summary form. Farmers, or their consultants (such as extension agents), could then use these data to inform their opinions on the merits of the practice of ICM. A farmer presumably would seek ICM data that somehow match the characteristics of his or her farm and examine the effects on input use and output levels. However, in this report, we assume that the ICM program is offered as the design stage of a larger program.

A Partial Equilibrium Model

Before presenting the recommended cost-benefit model, a broader partial equilibrium model is presented. We present this partial equilibrium model in order to highlight what we consider to be the sectors of the economy most likely to be affected by an ICM program. Furthermore, the partial equilibrium model serves to highlight both the assumptions required by the recommended cost-benefit model and the types of errors that would arise should these assumptions prove false.[2]

The foundation of the partial equilibrium model is a profit function that includes these four components:

i) Producers of agricultural outputs (farmers).
ii) Suppliers of agricultural inputs.
iii) Consumers of agricultural outputs.
iv) Users of environmental services (who benefit from better environmental quality).

The optimal policy would then solve:

$$\Omega = \max_{H} \sum_{s=1}^{\infty} \left[\Pi_A(P_I,P_A,Z_A,H) + \Pi_I(P_I,P_A,Z_I,H) + CS(P_A,Z_{CS}) + E(P_A,P_I,Z_E,H) \right] e^{-\rho s} \tag{1}$$

where:

Π_A = Profit (producer surplus) to agricultural sector, presumed to be a function of agricultural prices (P_A), input prices (P_I), other factors (Z_A) (including farm characteristics and agricultural technologies available), and the ICM subsidy (H). Note that P_A and P_I are vectors corresponding to the range of different crops that can be grown and the range of agricultural inputs that can be purchased. H influences producer surplus through its effects on the mix of inputs chosen.

Π_I = Profit to farm input suppliers, presumed to be a function of P_A, P_I, H, and other factors (Z_I). H influences producer surplus via its effects on factor demand. Π is a profit vector (i=1,..,I) for different input suppliers, including suppliers of ICM inputs and suppliers of agricultural chemicals.

[2]Note that this partial equilibrium model, while more general than a cost-benefit approach, is itself a simplification of some general equilibrium, economy-wide model.

CS = Aggregate consumer surplus, presumed to be a function of P_A and other factors (Z_{CS}), such as income and personal tastes. Note that although H is not included in CS, it could enter as an income effect.

E = Environmental quality benefits, presumed to be a function of P_A, P_I, H, and other factors. The relationship of P_A, P_I, and H to environmental quality is indirect and is achieved as a byproduct of their influence on the intensity of agriculture.

ρ is the social discount rate, so Ω is a net present value. Note that, without loss of generality, we assume constancy of prices and other factors over time.

As an equilibrium problem, this model is formulated in terms of price, with Z variables exogenous. We assumed that P_I and P_A are endogenously determined and that policymakers can affect the level of the ICM subsidy (H). Thus, farmers and consumers are price takers, but farmers may be able to lower the effective price of certain inputs by participating in an ICM program.

In a competitive economy, where information is universally available and there are no market distortions and no externalities, the policymaker need not interfere, and H can be set to zero. The need for interference is therefore a function of E, the externality of environmental quality benefits. Without Government interference, E will be too low if there is a negative externality. With Government interference, an increase in environmental quality benefits can be achieved with a relatively small net loss in the other three components.

ICM (as currently implemented) changes the effective price schedules of certain elements of P_I. Each farmer participating in the program receives partially subsidized prices for certain inputs. The existence of the partial subsidy, holding only over a certain range of input quantities, suggests a slight reformulation of the model. The choice of input mix can be associated with a discrete production technology. Thus, we model the vector of inputs used as I(t), where t indicates a particular production technology.[3] In this context, H is a function of the technology chosen, with H greater than zero when an ICM technology is adopted.

Each of the t=1,..,T production technologies is associated with a unique vector of inputs.[4] The cost to the farmer of choosing a particular technology is also a function of the level and price of this vector of inputs and of the ICM subsidy associated with this technology, H_t. Note that H_t could be a lump sum payment contingent on adoption of the technology, rather then a cost-share over a portion of input purchases.

Each farmer solves the following problem:[5]

$$\Pi_A^* = \Pi_A + H(t) = \max_t \left[P_A F_A(I(t),Z_A) - P_I I(t) + H(t)\right] \;;\; t=1,...,T \tag{2}$$

where I(t) is the vector of inputs associated with technology t, $F[I(t),Z_A]$ is a multioutput production function, and H(t) is the ICM subsidy awarded when technology t is adopted.[6] In equilibrium, the farmer's choice of

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[3]We use "technology" to refer to the entire set of inputs and cropping practices that describes a farmer's actions.

[4]In simple cases, this unique vector will be fixed. The adopted technology more generally determines the probability distribution of input uses.

[5]For ease of presentation, we abstract from the time dimension.

[6]This formulation assumes certainty. In an uncertain world, one maximizes the expected value of P_A F_A() - P_I I(t) + H(t), with the expectation taken over the probability density of I(t).

t is simultaneously determined with P_A and P_I. Note that P_I is a function of total input demand, as generated through the mix of technologies adopted by the agricultural sector. Furthermore, note that we separate H from Π_A because H is a transfer payment and should not appear in a social welfare function.

If we know P_I, then Π_I can be computed as:

$$\Pi_I = \sum_{i=1}^{I} \int_0^{P_i} S(P_i)dP_i \tag{3}$$

where $S(P_i)$ is the supply curve for input i. If we know P_A, CS can be computed as:

$$CS=\sum\left[\int_{P_A}^{P_{Amax}} D(P_A)dP_A\right] \tag{4}$$

where ∫ is an appropriate line integral, P_{AMAX} are cutoff prices, $D(P_A)$ is a multioutput demand system for agricultural products, and the summation is over all consumers in the population.

Lastly, E is a measure of the flow of benefits from the environment, which presumably increase as environmental quality increases. Agricultural practices can reduce benefits related to environmental quality.[7] Because input prices, crop prices, and the ICM subsidy influence the type and extent of agriculture, E is expressed as a function of price, rather than of inputs used.

The measurement of E is complicated by the lack of prices for the commodity "environmental quality." Instead, we need to find

$$E = \mathrm{M}\big(Q(P_A,P_I,H),P_A,P_{NA},U_o\big) - \mathrm{M}\big(0,P_A,P_{NA},U_o\big) \tag{5}$$

where M is the expenditure function, U_o is the reference utility level, $Q(P_A,P_I,H)$ is environmental quality (at equilibrium prices P_A and P_I and ICM subsidy H),[8] and P_{NA} are prices of all other (nonagricultural) commodities. We can also find the value of change in environmental quality, say from Q_0 to Q_1, by integrating the compensated demand curve, equal to dM/dQ by Shepard's lemma (Varian, 1984) from Q_0 to Q_1.

Without knowledge of the expenditure function, we have several means for discovering the value of E. First, one can ask individuals to declare their value of E, a process known as contingent valuation (Mitchell and Carson, 1989). Although attractive in its ability to give a direct estimate of E, contingent valuation suffers from a dependence on hypothetical behavior. In contrast, one can attempt to infer the value of E by examining actual behavior. For example, using the principle of weak complementarity (Freeman, 1979), priced commodities with demand curves that include environmental quality as an argument can be used for inference regarding E. Travel cost analysis and hedonic price analysis are examples of this class of revealed preference techniques. Although capturing the use value of environmental quality, these revealed preference techniques cannot measure the "existence" value of environmental quality, the value to people of knowing that

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[7]For example, application of agricultural chemicals and their subsequent runoff can pollute nearby streams. Fish populations will decrease as the result of this reduction in environmental quality. With fewer fish, fishermen will be less satisfied with their fishing experience.

[8]Note that we compare the level of Q to an arbitrary baseline of zero.

the environment is healthy, even if no particular use is made of these environmental services. A combination of contingent valuation and revealed preference techniques can be used to estimate the value of E.

The discussion above has abstracted from the costs of providing the ICM program. These costs will be twofold, administrative costs and the economywide inefficiencies due to taxation. These inefficiencies are due to the distortionary effects that income taxes and sales taxes have on relative prices. Thus, a dollar's worth of transfer payments has a nonzero effect on total social wealth.[9] Although we assume these administrative and efficiency costs to be small, inclusion of these costs is straightforward.

In summary, the partial equilibrium model discussed here has four components: two producer surplus components (one for the agricultural sector and one for the agricultural input sector) and two consumer components (one for agricultural products and one for environmental quality). Given proper demand and supply curves, we can estimate these components. However, these demand and supply curves may not be readily available, especially in detail sufficient to capture the potentially subtle effects of an ICM program. Therefore, we now discuss means of simplifying this model.

A Cost-Benefit Approach

When considering the effects of an ICM program, one may not need to fully implement the above partial equilibrium model. In particular, for a relatively small ICM program and a competitive global market in inputs and outputs, we can considerably simplify the process by focusing on the margin. In other words, current prices for inputs and outputs can be used as good measures of marginal costs and benefits to society.[10]

We can define the social cost of ICM as the value of additional resources used in the production of the preferred inputs (such as scouting services), less the value of resources freed from production of the substituted inputs (such as chemical applications), plus any resulting changes in the value of agricultural outputs. At the margin, price times quantity can be used to measure these values. Thus, the social cost of ICM can be expressed as follows:

$$SC_{ICM} = P_Y[Y_0 - Y_1] - P_A[A_0 - A_1] - P_B[B_0 - B_1] \tag{6}$$

where A represents non-ICM inputs, B represents ICM inputs such as pest scouting, Y is agricultural production, P is input and output prices, and subscript 0 is without ICM participation and subscript 1 is with ICM participation. We presume that $(A_0 - A_1)$ would be positive, $(B_0 - B_1)$ would be negative, and $(Y_0 - Y_1)$ would be indeterminant. We then reformulate the expression as follows:

$$\begin{aligned} SC_{ICM} &= [(P_Y \times Y_0) - (P_A \times A_0) - (P_B \times B_0)] - [(P_Y \times Y_1) - (P_A \times A_1) - (P_B \times B_1)] \\ &= \qquad\qquad \Pi_0 \qquad\qquad - \qquad\qquad \Pi_1 \end{aligned} \tag{7}$$

In other words, the social cost of ICM can be assessed simply by measuring the change in farm profits. The ICM subsidy is excluded because it is merely a transfer payment.[11]

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[9]Note that this argument is strictly one of efficiency, and is abstract from other social goals.

[10]The existence of extensive agricultural programs will distort observed market prices for both inputs and outputs, in the sense that they do not necessarily measure full social cost or benefit.

[11]The focus is on economic efficiency, abstracting from other social goals. Costs associated with program administration have been omitted. These costs are assumed to be small, and their inclusion in the benefit-cost calculation would be relatively straightforward.

In a controlled experiment, the change in profit should be fairly easy to measure. However, in the real world, there are many influences on farm profitability that, at best, can only be partially controlled for. For example, an increase in crop prices, or unusually good weather, might yield a temporary increase in profit that has nothing to do with adoption of an ICM technology.

A larger problem facing cost-benefit analysis is the determination of the benefit of environmental quality improvements. The following questions need to be resolved:

1. What physical effects, in terms of chemical loadings, will an ICM program create?
2. What are the ecological effects of these physical effects?
3. How does society value these ecological effects?

Because questions one and two are outside the domain of economics, we must rely on geophysical and biological scientists to provide us with reasonable models. As social scientists, our responsibility is to address question three. However, the valuation process may be difficult.

How might one measure the environmental benefits of an ICM program? As a first-order approximation, these benefits can be divided into three broad categories: health benefits, recreation benefits, and existence values.

- **Health benefits**. With reductions in chemical applications, human exposure to these potentially harmful substances will decrease. Potential beneficiaries include both farmworkers and the general population. For each group, we need to know the value of reduced health risk, assuming that we know the level of this reduction (if our physical and biological models are accurate). For onfarm workers, hedonic analysis of wage rates under different work environments is one means by which this value can be ascertained. Similar techniques, such as measures based on risks of the same magnitude as those posed by agricultural chemicals, can be used for the general population.[12]

- **Recreation benefits**. Recreation benefits include many nonagricultural uses of the rural landscape. For example, wildlife populations may be reduced because of increased chemical loadings, diminishing recreational activities. The qualitative nature of agricultural effects, and the diffuse participation pattern of the types of recreation most likely to be affected by these agricultural effects, complicate measurement efforts. In particular, the common technique for measuring recreational benefits, travel cost analysis, was devised for measuring the total value of identifiable sites located at discrete points in space. To address our problem, variants of the travel cost model, such as hedonic travel cost model (Brown and Mendelsohn, 1984) for measuring qualitative differences, or multiple-site travel cost (Burt and Brewer, 1971) for measuring the value of a system of sites, may be useful. Alternatively, hedonic analysis of housing prices may be useful, given that the rents associated with environmental quality are captured by housing prices. Note that the hedonic price approach can also be used to measure health benefits.[13]

- **Existence value**. The protection of the ecological health of the planet may be of value to society for reasons unrelated to human uses of the environment. For example, the continued existence of an endangered species may have value to many individuals, even though they will never see or otherwise use the species (Greenley, Walsh, and Young, 1982). Because these existence values are pure public goods that are not complementary with any marketed goods, some form of contingent

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[12]Among other considerations, the involuntary nature of the exposure faced by the general population suggests somewhat different measures than the measures used for farmworkers.

[13]Hedonic analysis of housing prices can be used to estimate the value of the quality of the environment surrounding the property, where this value comes from proximity to amenities (such as outdoor recreation) and proximity to undesirable features (such as polluted water).

valuation is required. However, care must be taken not to double count. In particular, the protection of future productivity, a possible outcome of widespread adoption of ICM technology, should not be part of existence value. Rather, the protection of future productivity should appear as part of the net present value of agricultural outputs, with adjustments for differences between private and social discount rates and for changes in land capacity (Z_A) as a function of input decisions in prior years.[14]

In summary, the change in farm profits can be used as a measure of the social costs of a moderately sized ICM program. Benefit measures are more problematic. First, noneconomic information on the physical and biological changes given adoption of an ICM program are required. Second, valuation of these changes is necessary, a valuation complicated by the lack of prices for commodities such as environmental quality.

Data Needs

Implementing the cost-benefit analysis of ICM requires two sets of information. The first describes the value of changes in the environment. Much of this information describes the biophysical effects of an ICM program and is beyond the scope of economic analysis. Valuation of these effects is within the scope of economic analysis, but will often be of a more general nature than is likely to be gathered by the administrators of the ICM program. For example, hedonic price measures in rural housing markets, visitation data to recreational sites, and contingent value surveys can be used to estimate some of the benefits of an ICM program. Note that ancillary sources of information will probably have to be used, such as value-of-life measures or recreational visitor/day measures.

The second set of data pertains to producer actions. Information on farm profitability is especially needed, encompassing measures of input use and output production. The goal is to construct a model of farm behavior, based on input and output prices, farm characteristics, and the presence of Government programs. The model, such as a profit function, is then used to derive factor demand and output supply. Note that inputs could be incorporated on an input-by-input basis or as components of a set of discrete technologies with the farmer selecting a technology rather than individual input levels.

The effects of Government programs can then be simulated through the model. For example, a price subsidy could be incorporated by reducing the price for the favored inputs (such as scouting services). The model would then predict input demand and output production. The social cost of the program could then be calculated by multiplying these new inputs and outputs by the true (nonsubsidized) price, and comparing the resulting social net profit to the profit achieved when prices are not subsidized. Note that price subsidies should lead to private profits at least as good as those realized without the subsidies. However, a portion of these profits are Government transfers and do not reflect actual gains to society. Thus, the use of preprogram prices for measurement of social cost is required.

To ascertain whether the program is in fact reducing chemical use from what it would have been in the absence of the program, several data items must be collected from those who enroll in the program. These data could be considered the minimum data collection goal:

1. Rotation prior to ICM.
2. Chemical use for each crop in the rotation, including when applied and how applied.
3. Yield each year of rotation and yield goal.
4. Statement that rotation would have been continued in absence of ICM.
5. Details of ICM plan, including rotation, chemicals used, amounts, how applied, and yield goals.
6. In followup, recommended and actual chemical use.

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[14]This relationship introduces a dynamic element into the maximization problem. One way of simplifying this problem is to consider technologies as defined over time, so that a technology describes decisions over the entire planning horizon, and the vectors of yearly outputs are a function of this multiyear technology.

If an evaluation of producer finances under ICM is desired, the following data are required to estimate profit functions:

7. Amounts of other inputs used before ICM (labor, fuel, machinery, tillage) and prices.
8. Use of other inputs under ICM plan.

If environmental effects are to be evaluated, the following data that enable calculation of runoff and leaching should be collected:

9. Geographic or other link that enables one to tie field data to soils data so that vulnerability can be ascertained and to the watershed so that demand for environmental services can be assessed.
10. Conservation practices employed.
11. Hydrologic condition of soil cover.
12. Hydrologic soil group.

The Objective Yield Survey provides a good template for much of the above information, especially because it allows comparison with a large control group.

Summary

Starting with a descriptive partial equilibrium model of the agricultural sector, a cost-benefit framework for analysis of the ICM program is recommended. Assuming that a small ICM program will not cause large national changes, the cost-benefit model should capture most of the effects without necessitating complex derivation of relevant demand and supply curves. Within a cost-benefit analysis, three broad area categories can be identified: environmental effects, changes in output, and changes in input demand.

The cost-benefit analysis must consider the benefit of environmental improvements. However, because of environmental quality's public good nature, finding direct measures of its value is difficult. In other words, price information on the incremental value of an enhancement of environmental quality is not available.

Instead, indirect measures of the value of environmental quality improvements are necessary. Such measures might be based on hedonic price analysis, contingent valuation, or a travel cost analysis. Little work has been done in the dispersed, rural setting within which most of the benefits of an ICM program are likely to occur.

While the environmental component may be the most difficult to measure, changes in output and input are not trivial. The largest problem is the control of random fluctuations, as by inclusion of a control group in the study design. The lack of such control complicates determining whether observed changes are the result of the adoption of an ICM technology, or the result of unrelated changes in the economic and physical environment. Furthermore, given the multiyear nature of many ICM programs (based on changes in rotations), single-year data are probably inadequate for thorough analysis.

In an ideal situation, we would obtain multiyear data for both ICM participants and for similar farmers who are not participants. Such data would include measures of costs and profits, and physical measures (such as pounds of fertilizer used and bushels of output). A profit function could then be computed, providing a general means of modeling the physical and economic effects of Government policies (such as an ICM program).

Without such measures, we must use county averages, both for ICM and non-ICM farmers for preliminary analysis. The use of averages provides a basis for before/after comparisons and lessens the difficulties of not having multiyear data. These averages can then be compared in a qualitative fashion by examining whether means are statistically different and looking at proportional changes.

ICM program analysis needs to consider both environmental effects and changes in input and output. Under reasonable assumptions, these effects can be modeled with a cost-benefit approach. However, this approach still requires measures of environmental benefits and better data on farm production. Lacking such data, we can provide qualitative analysis, with the aim of indicating the general direction of changes that might occur if an expanded ICM program were adopted.

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